OPTIMIZE THE PRODUCTION OF CHARCOAL FROM LOCAL BIO-MATERIAL

UMI NAJWA MAULAD MOHD NOOR

BACHELOR OF CHEMICAL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

ABSTRACT

Charcoal is the dark grey residue produced by slow pyrolysis consists of carbon and ash. It is usually used for art, medicine, filter and fuel. The charcoal can be produced from any agricultural waste like wood, coconut shells and others. Coconut charcoal, however, is widely used for the high quality activated carbon. This research aims to optimize the production of charcoal by carbonization process. The objectives of this research are to find the optimum condition in producing the coconut based charcoal and to analyze the weight loss and the functional group of the charcoal. The production of charcoal was carried out at different carbonization temperature and different time range. The product was analyzed using FTIR. The results shown that the weight of the product decreased with increase in time and temperature. It was found that the optimum condition for producing charcoal is 450^{o}C and 10 min. It was also found that the functional groups appeared are alkanes, alkenes and alkynes based on FTIR analysis.

ABSTRAK

Arang adalah bahan baki kelabu gelap yang dihasilkan oleh pirolisis perlahan yang terdiri daripada karbon dan abu. Ia biasanya digunakan untuk alatan seni, perubatan, penapisan dan bahan api. Arang boleh dihasilkan daripada bahan buangan pertanian seperti kayu, tempurung kelapa dan lain-lain. Arang kelapa, bagaimanapun, digunakan secara meluas untuk menghasilkan karbon aktif yang berkualiti tinggi. Kajian ini bertujuan untuk mengoptimumkan penghasilan arang berdasarkan proses karbonisasi. Objektif kajian ini adalah untuk mencari keadaan optimum dalam menghasilkan arang berasaskan kelapa dan menganalisis kehilangan berat serta kumpulan berfungsi arang. Penghasilan arang ini dijalankan pada suhu karbonisasi dan jarak masa yang berbeza. Produk yang terhasil dianalisis menggunakan FTIR. Hasil kajian menunjukkan bahawa berat produk menurun dengan peningkatan dalam masa dan suhu. Ia didapati bahawa keadaan optimum untuk menghasilkan arang ialah pada suhu $450^{o}C$ dan 10 minit. Kumpulan berfungsi yang wujud adalah alkana, alkena dan alkina berdasarkan analisis daripada FTIR.

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LIST OF ABBREVIATIONS

^oC	-	degree Celsius
	-	
%	-	Percentage
g	-	gram
cm^{-1}	-	Wavenumber
mm	-	millimetre
cm	-	centimeter
min	-	minute
I	-	iodine
Br	-	bromine
Cl	-	chlorine
H	-	hydrogen
F	-	fluorine
EFB	-	Empty fruit bunch
PAC	-	powder activated carbon
GAC	-	granular activated carbon
ZDDP	-	zinc dialkyl dithiophosphate
IR	-	Infrared
SEM	-	scanning electron microscope
FTIR	-	Fourier Transform Infrared Spectrometer
TPD	-	temperature programmed desorption
XPS	-	X-ray photoelectron spectroscopy
NMR	-	nuclear magnetic resonance

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF RESEARCH

Charcoal is the dark grey residue consisting of carbon and any remaining ash obtained by removing water and other volatile constituents from animal and vegetation substances. Charcoal can be produced from any agricultural waste and was encourage the use of biomass resources that has no other value (unsuitable for animal or human consumption or composting) such as wood, sawdust, bagasse (dried sugar cane), corn cobs, palm fronds and coconut shells [Manpreet Singh et. al., 2010]. It is usually produced by slow pyrolysis by heating of wood or other substances in the absence of oxygen. Some of the widely used raw materials are bagasse, sawdust, coconut husk, coconut shell and oil palm shell [Neil Noble, 2002]. Charcoal has been used since earliest times for a range of purposes including art, medicine, filter and fuel. Charcoal also has been an important domestic product for many years. Its greatest use is for home and outdoor recreational cooking. Besides, it is also used in the manufacture of carbon disulfide, carbon tetrachloride, sodium cyanide and other industrial chemicals. Other than that, charcoal also can be converted to activated carbons and other industrial uses [Arlie W. Toole et. al., 1961].

The charcoal can be classified into three common types such as briquette, lump and extruded based on its size and shape, its process and each type has its specific application. The choices of raw materials to produce the charcoal are depending on their price and stability of supply and potential extent of activation.

Coconut shells are the abundant waste-product from the coconut oil and desiccated coconut industry and in most tropical countries after taking its water for drinking and fiber for fatty oil. It is said that charcoal manufactures from coconut shell and converted into activated carbon is considered superior to those obtained from other sources. It is because of small macropores structure which renders it more effective for the adsorption of gas and vapor and for the removal of color, oxidants, impurities and odor of compounds. It has been the most popular feed stock for the activated carbon production.

In this study, the optimal condition in producing the charcoal is determine through experiment using any kind of local bio-material products. The variables include the temperature and holding time. The analysis for the charcoal is using Fourier Transform Infrared Spectrometer (FTIR) which is to know the functional groups appeared in the samples.

1.2 PROBLEM STATEMENT

The optimal operating condition in producing charcoal is not well known in production processes. According to the paper written by Gratuito et al., 2008, basically, the production of the product is only for the requirement of the users not for the manufacturers' side like the cost of process utilities. So, this research is to study about the optimum operating condition of the production of the charcoal. Besides, as said in paper written by Tan et al., 2008, about 151,000ha of land in Malaysia was being used for coconut plantation in 2001. In 2009, the production of coconuts in Malaysia is about 555,120 tonnes per year. So, the wastes from this plantation are too much. This study is also necessary to overcome the waste problems.

1.3 OBJECTIVE

The objectives of this study are:

i) To find the optimum condition in producing the charcoal by considering the temperature and time.

ii) To analyze the weight loss of the charcoal and also the functional groups appeared.

1.4 RESEARCH SCOPE

In general, the scopes of this research are as following:

i) The preparation of the charcoal using local bio-material such as coconut shell by experimental process.
ii) The variables for this experiment are holding time and temperature.
iii) The method used to produce the charcoal is using carbonization process.
iv) The optimal condition in producing charcoal and the comparison of the functional groups appeared for each samples.

1.5 RATIONAL AND SIGNIFICANCE

Charcoal has many usages by itself but when it is being activate and become activated carbon, it has lots more usage. Activated carbon is one of the important adsorbent in many applications. This research is necessary for the charcoal and activated carbon’s industry because knowing the optimum operating conditions of the production gives lots of advantages such as reducing the utilities cost and time of production but increasing in the properties of the production of the charcoal. Besides, the production of the waste from bio-material such as coconut shell, coconut husk, palm oil sludge and empty fruit bunch (EFB) also being one of the problems in this country. So, this study also will be one of the ways to manage the waste from being abundant and to convert them to become useful.

CHAPTER 2

LITERATURE REVIEW

2.1 CHARCOAL

Charcoal is an impure carbon as it contains ash. It is obtained by heating wood until its complete pyrolysis (carbonization) occurs, leaving only carbon and inorganic ash. In many parts of the world, charcoal is still produced semi-industrially, by burning a pile of wood that has been mostly covered with mud or bricks. The limited supply of oxygen prevents the charcoal from burning. A more modern alternative is to heat the wood in an airtight metal vessel, which is much less polluting and allows the volatile products to be condensed.

Pyrolysis is a thermochemical decomposition of organic material at elevated temperature without the participation of oxygen. It involves the simultaneous change of chemical composition and physical phase and is irreversible. It is a special case of thermolysis and is the most commonly used for organic materials. In general, pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content, char. Extreme pyrolysis, which leaves mostly carbon as the residue is called carbonization. The process is used heavily in the chemical industry to produce charcoal, activated carbon, methanol, and other chemicals. It also used to convert waste into safely disposable substances. Besides, it can be called in various names such as dry distillation, destructive distillation or cracking. Pyrolysis is different from other high-temperature processes like combustion and hydrolysis because it does not involve reactions with oxygen, water or any other reagents.

Charcoal produced under well-controlled carbonization conditions may be hard and brittle, or comparatively soft and crumbly, when rubbed and handled. In weight, it may be rather heavy to quite light. This physical property is related to the weight of the dry wood of the various species, which in a given volume may be heavy (sugar maple, beech, oaks and longleaf pine; average specific gravity of 0.63), medium (elm, alder, ash, soft maple and jack pine; average specific gravity of 0.48) and light (cottonwood and most softwoods; average specific gravity of 0.39). Well-prepared charcoal weighs about one-third as much as wood and is reduces to roughly one-half of the volume of wood. The apparent specific gravity of charcoal ranges from about 0.2 to 0.5, depending on the specific gravity of wood from which it was made.

Charcoal has been used since the earliest times for a range of purposes including art and medicine, but by far its most important use has been a metallurgical fuel. Charcoal is the traditional fuel of a blacksmith's forge and other applications where an intense heat is wanted. It was also used historically as a source of carbon black by grinding it up. In this form, charcoal was important to early chemist and was a constituent of formulas for mixtures such as gunpowder. Due to its high surface area, charcoal can be used as a filter, as a catalyst or as an absorbent.

2.1.1 Characteristic Of Charcoal

There are some characteristic of the charcoal that can be analyze such as moisture content, volatile matter, fixed carbon content and ash content.

Charcoal fresh from an opened kiln contains very little moisture, usually less than 1 %. Absorption of moisture from the humidity of the air itself is rapid and there is, with time, a gain of moisture which even without any rain wetting can bring the moisture content to about 5-10 %, even in well-burned charcoal. When the charcoal is not properly burned or where pyroligneous acids and soluble tars have been washed back onto the charcoal by rain, as can happen in pit and mound burning, the hygroscopitity of the charcoal is increased and the natural or equilibrium moisture content of the charcoal can rise to 15 % or even more. Moisture is an adulterant which lowers the calorific or heating value of the charcoal, where charcoal is sold by weight, keeping the moisture content high by wetting with water is often practiced by dishonest dealers. The volume and appearance of charcoal is hardly changed by addition of water. For this reason bulk buyers of charcoal prefer to buy either by gross volume, e.g. in cubic meters, or to buy by weight and determine by laboratory test the moisture content and adjust the price to compensate. In small markets sale is often by the piece. It is virtually impossible to prevent some accidental rain wetting of charcoal during transport to the market but good practice is to store charcoal under cover even if it has been bought on a volume basis, since the water it contains must be evaporated on burning and represents a direct loss of heating power. This occurs because the evaporated water passes off into the flue and is rarely condensed to give up the heat it contains on the object being heated in the stove. Quality specifications for charcoal usually limit the moisture content to around 5-15 % of the gross weight of the charcoal. Moisture content is determined by oven drying a weighted sample of the charcoal. It is expressed as a percentage of the initial wet weight. There is evidence that charcoal with high moisture content (10 % or more) tends to shatter and produce fines when heated in the blast furnace, making it undesirable in the production of pig iron.

The volatile matter other than water in charcoal comprises all those liquid and tarry residues not fully driven-off in the process of carbonization. When the carbonization temperature is low and time in the retort is short, then the volatile matter content increases. These effects are reflected in the yield of charcoal produced from a given weight of wood. At low temperatures (300 ^{o}C) a charcoal yield of nearly 50 % is possible. At carbonization temperatures of 500-600 ^{o}C volatiles are lower and retort yields of 30 % are typical. At very high temperatures (around 1,000 ^{o}C) the volatile content is almost zero and yields fall to near 25 %. As stated earlier, charcoal can reabsorb tars and pyroligneous acids from rain wash in pit burning and similar processes. Thus the charcoal might be well burned but have high volatile matter content due to this factor. The volatile matter in charcoal can vary from a high of 40 % or more down to 5 % or less. It is measured by heating away from air, a weighed sample of dry charcoal at 900 °C to constant weight. The weight loss is the volatile matter. Volatile matter is usually specified free of the moisture content. High volatile charcoal is easy to ignite but may burn with a smoky flame. Low volatile charcoal is difficult to light and burns very cleanly. A good commercial charcoal can have a net volatile matter content -

(moisture free) of about 30 %. High volatile matter charcoal is less friable than ordinary hard burned low volatile charcoal and so produces fewer fines during transport and handling. It is also more hygroscopic and thus has higher natural moisture content.

The fixed carbon content of charcoal ranges from a low of about 50 % to a high of around 95 %. Thus charcoal consists mainly of carbon. The carbon content is usually estimated as a "difference", that is to say, all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the per cent of "pure" or "fixed" carbon. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce metal. But the industrial user must strike a balance between the friable nature of high fixed carbon charcoal and the greater strength of charcoal with a lower fixed carbon and higher volatile matter content to obtain optimum blast furnace operation.

Ash is determined by heating a weighed sample to red heat with access of air to burn away all combustible matter. This residue is the ash. It is mineral matter, such as clay, silica and calcium and magnesium oxides, etc., both present in the original wood and picked up as contamination from the earth during processing. The ash content of charcoal varies from about 0.5 % to more than 5 % depending on the species of wood, the amount of bark included with the wood in the kiln and the amount of earth and sand contamination. Good quality lump charcoal typically has an ash content of about 3 %. Fine charcoal may have very high ash content but if material less than 4 mm is screened out the plus 4 mm residue may have an ash content of about 5-10 %.

2.1.2 Activated Carbon

The word activated in the name due to its high degree of micro porosity which is 1 gram of activated carbon has a surface area in excess of 500 m^2 which is about one tenth the size of an American football field. Activated carbon has been used since the early part of the 20^{th} century for water and wastewater treatment [Kalderis et al., 2008], water purification, volatile organic chemicals and pesticide residual removal. It is also called activated charcoal or activated coal which is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area for adsorption or chemical reactions. It removes pollutants by capturing chemical compounds on the porous surfaces. A carbon with large holes would be best at picking up heavy organic chemicals, while smaller pores would catch the lighter pollutants [Engber, 2005]. Carbon has a natural affinity for organic pollutants like benzene through adsorption which bind to its surface. If the carbon is “activate”, at higher temperature, it will form pores that increase its surface area. The shape of the activated carbon looks like beehive which absorbs the pollutant fast. This activated carbon is increasingly used as an economic and stable mass separation agent for the removal of surfactants to raise the final product quality in many industrial processes. Besides, it also plays an important role in many areas of modern science and technology such as purification of liquids and gases, separation of mixtures and catalysis [Kang et al., 2006].

The activated carbons are high porosity, high surface area materials, manufactures by carbonization and activation of carbonaceous materials. It can be design for adsorption of specific adsorbate using appropriate precursor and by optimizing the activation process conditions [Srinivasakannan and Zailani, 2004]. Though relatively expensive, activated carbon has been widely used for the removal of impurities in food products and its production has been significantly increased ever since it has been used in the production of municipal tap water [Kim, 2010].

Activated carbon presents a group of well-established, universal and versatile adsorbents. The characteristic in choosing the types include pore structure, particle size, and total surface area and void space between particles [Steve and Erika, 1998]. The activated carbons are complex products which are difficult to classify on the basis of their behavior, surface characteristics and preparation methods. Mostly, it has been classified based on the physical characteristics such as powder activated carbon (PAC), granular activated carbon (GAC), impregnated carbon, and others. The GAC version is mostly used in water treatment which can adsorb soluble substances such as adsorption of organic, non-polar substances (mineral oil, BTEX, Poly aromatic hydrocarbons (PACs) and (Chloride) Phenol), adsorption of halogenated substances (I, Br, Cl, H and F), odor, taste, yeasts, various fermentation products and non-polar substances.

Figure 2.1: Activated Carbon

Under scanning electron microscope (SEM), the high surface area structures of activated carbon are revealed. These micro pores provide superb conditions for adsorption to occur since adsorbing material can interact with many surfaces simultaneously. Physically, activated carbon binds materials by van der Waals force or London dispersion force but it does not bind well to certain chemicals including alcohols, glycols, strong acids and bases, metals and most inorganics.

There are several properties of activated carbon that usually be analyzed:

a) <u>Iodine number</u>

Iodine number is the most fundamental parameter used to characterize activated carbon performance. It is a measure of activity level which is the higher number indicates higher degree of activation, often reported in mg/g in range of 500-1200 mg/g. it is a measure of the micro pore content of the activated carbon by adsorption of iodine from solution. It is equivalent to surface area of carbon between 900 m^2/g and 1100 m^2/g which is the standard measure for liquid phase applications.

Basically, iodine number is a measure of the iodine adsorbed in the pores. In water treatment carbons have iodine number ranging from 600 to 1100. Naturally, this parameter is used to determine the degree of exhaustion of a carbon in use. However, this practice should be viewed with caution as chemical interaction with the adsorbate may affect the iodine uptake giving false results. It is recommended if it has been shown to be free of chemical interactions with adsorbates and if an experimental correlation between iodine number and the degree of exhaustion has been determined for the particular application.

b) ***Molasses***

Molasses number is a measure of the mesopore content of the activated carbon by adsorption of molasses from solution. A high molasses number indicates a high adsorption of big molecules in range of 95-600. It is also a measure of the degree of decolorization of a standard molasses solution that has been diluted and standardized against standardized activated carbon. Due to the size of color bodies, the molasses number represents the potential pore volume available for larger adsorbing species. As all of the pore volume may not be available for adsorption in a particular wastewater application, and some of the adsorbate may enter smaller pores, it is not a good measure of the worth of a particular activated carbon for a specific application. Frequently, this parameter is useful in evaluating a series of active carbons for their rates of adsorption.

c) ***Methylene blue (MB)***

Some carbons have a mesopore structure which adsorbs medium size molecules such as the dye methylene blue. The adsorption is reported in g/100g which is in range of 11-28g/100g.

d) ***Hardness***

It is a measure of the activated carbon's resistance to attrition. It is important indicator of activated carbon to maintain its physical integrity and withstand frictional forces imposed by backwashing, etc. there are large differences in the hardness of activated carbons, depending on the raw material and activity level.

e) ***Ash content***

It reduces the overall activity of activated carbon and efficiency of reactivation. The metal oxides (Fe_2O_3) can leach out of activated carbon resulting in discoloration. Acid/water soluble ash content is more significant than total ash content. Soluble ash content can be very important for aquarists as ferric oxide can promote algal growths. A carbon with low soluble ash content should be used for marine, freshwater fish and reef tanks to avoid heavy metal poisoning and excess plant/algal growth.

f) ***Particle size distribution***

The finer the particles size of an activated carbon, the better the access to the surface area and the faster the rate of adsorption kinetics. In vapor phase systems this needs to be considered against pressure drop which will affect energy cost. Careful consideration of particle size distribution can provide significant operating benefits.

2.2 MAJOR PROCESSES

The carbonization process is the major process in producing the charcoal. It is includes drying and heating to separate by-products, including tars and other hydrocarbons from raw materials, as well as to drive off any gases generated. The process completed by heating the material over 400 ^{o}C in an oxygen-free atmosphere that cannot support combustion. The carbonization step is also a process where the carbon material is pyrolyzed at temperature in range of 600-900 ^{o}C under inert atmosphere.

According to Neil Noble, 2002, the process is divided into four stages which are combustion, dehydration, exothermic reaction and cooling. The oxygen is supply in combustion process and the temperature rises from ambient to over 500 ^{o}C. When the fire is established, the oxygen supply is reduced after the firing point is closed and temperature drops to about 120 ^{o}C. Free water is driven out at a reduced temperature of about 100 ^{o}C and the kiln gives out thick, white and moist steam. When the wood has dried, temperature rise to about 280 ^{o}C and the wood begin to break down into charcoal, water vapor and other chemicals. The smoke at this stage is yellow, hot and oily and the temperature is maintained by controlling the air flow through holes and vents to help burn more wood. After the carbonization is complete, the kiln cools to below 100 ^{o}C and charcoal can be removes for further cooling. It is also said that the process of carbonization is greatly dependent on the carbonization temperature, the moisture content of the wood (the drier the better), the skill of the producer and the condition of the wood (lignin content).

2.2.1 Raw Material

There are lots of raw materials that can be used to produce charcoal and the most research interest is in agricultural by-products such as rubber seed coat, pecan shell, corncob, bamboo and oil palm fiber [Tan et al., 2008]. The selection of the raw material is depends on the design specifications since different raw material will produce the different properties of charcoal. The annual global production of 800 million tonnes of sugarcane results in 240 million tonnes of bagasse while the estimates annual world rice production is about 571 million tonnes resulting in approximately 140 million tonnes of rice husk available annually for utilization [Kalderis et al., 2008].

In most literature, it said that, in the recent years, the interest in the production of charcoal from agricultural by-products and residual wastes such as coconut shells are increasing because of their availability to be acquired. The coconut shells are the waste product of most of the tropical countries and the production from this material is more financially viable [Gratuito et al., 2008]. In 2009, it is reported that the coconut palms are grown in more than 80 countries of the world with total production of 61 million tonnes per year. For example, a number of chemical and physical processes such as flocculation, chemical coagulation, precipitation, ozonation and adsorption have been widely used to treat dye bearing wastewaters. However, the adsorption onto activated carbon (from charcoal) has been found to be superior compared to other techniques for wastewater treatment in terms of its capability for efficiently adsorbing a broad range of adsorbates and its simplicity of design. The commercially activated carbon is still considered expensive due to the used of non-renewable and relatively expensive starting material such as coal. Therefore, this has prompted a growing research interest in the production of activated carbons from renewable and cheaper precursors which is from industrial and agricultural by-products.

Figure 2.2: Raw Coconut Shells

Coconut shells are the abundant waste-product from the coconut oil and desiccated coconut industry and in most tropical countries after taking its water for drinking and fiber for fatty oil. According to Gratuito et al., 2008, the production of activated carbon from these material more financially viable since using grain or coal as raw materials, required extra amount of money for procurement. Coconut shell activated carbons have more advantages over other carbons materials besides of being a form of carbon that can absorb many gases, vapors and solid. It is because of its high density, high purity, virtually dust-free nature, harder and more resistant to attrition. It has been the most popular feed stock for the activated carbon. Activated carbon made of coconut shells has generally been proven to have superior adsorptive capability in liquid and gaseous phase application due to its properties such as high micro porosity, hardness, and high density, low ash content, more resistant to attrition and longer service life.

According to the most reliable names of international activated carbons supplier, Effigen Sdn. Bhd., based on their procedure, an average of 3.3 tons raw material is used to produce 1 ton of charcoal and 3 tons of charcoal will produce about 1 ton of activated carbon. Coconut shell is the only raw material used to produce activated carbon from this company.

2.2.2 Equipment for Making Charcoal

Charcoal has been made ever since the first metallurgic processes were discovered and provided the heat needed for working and smelting Bronze, Copper, Iron, Silver and to manufacture of glass. It was produced in the woods on leveled ground the charcoal clamps being protected from the wind in the woods. A charcoal stack was built around a chimney and covered with straw or bracken covered with earth and then lit at the top of the stack, allowed to burn and controlled by covering air holes with earth. The process took days and had to be watched day and night. When the carbonization was complete, the charcoal was quenched with steam (Arlie W. Toole et. al., 1961). Then, the methods of charcoal burning improved. It is using large metal retort (refer Figure A in appendix), a greater quantity of charcoal could be produced.

Kilns are one of the traditional charcoal productions which acquired skill. The most critical factor in the efficient conversion of wood to charcoal is the careful operation of the kiln. Wood must be dried and carefully stacked to allow an even flow of air through the kiln and sufficient time for reactions to take place. If kilns not operated correctly, yields can be half the optimum level. There are four types of kilns which are traditional kilns, brick and concrete kilns, portable steel kilns and mini-charcoal kilns (Neil Noble, 2002). Refer to Figure B to Figure E in appendix.

2.2.3 Parameters

There are about two variables in production of charcoal which are holding time and carbonization temperature.

a) Time

The duration of the carbonization has a significant effect on the development of the carbon's porous networks. The time should be enough to eliminate all the moisture and most of the volatile components in the precursor to cause pores to develop. Longer durations cause enlargement of pores at the expense of the surface area and also the control of the carbonization time is of economic interest since shorter times are generally desired as it equates to reduction in the energy consumption [Gratuito et al., 2008].

b) Carbonization Temperature

The application of heat to an impregnation material further accelerates the thermal degradation and the volatilization process which leads to development of pores, increase of surface area and the subsequent mass loss. The selection of the carbonization temperature is based on several factors which include the type of raw materials. For the different biomass precursors, it in range of 400 to 800 ^{o}C [Diao et al., 2002] while for coal-based materials can go as high as 900 ^{o}C [Karacan et al., 2007]. The optimum carbonization temperature for higher surface area was found to be 500 ^{o}C for rubber wood sawdust [Srinivasakannan and Zailani, 2004]. Temperature lower than 500 ^{o}C for grain sorghums produces micro porous carbons but with small surface areas while temperature higher than 600 ^{o}C yielded mesoporous carbons with high surface areas [Diao et al., 2002].

2.3 TYPES OF CHARCOAL

Charcoal is used as a type of fuel, most commonly to fuel grills for cooking. There are several different types of charcoal can choose from, with the most common types being briquette, lump, and extruded.

Among the briquette variety, there are several different types of charcoal. Generally, the briquette is made from a combination of charcoal, mineral carbon, brown coal, borax, sodium nitrate, sawdust, limestone, and starch. Each of these ingredients has its own special properties to contribute to the charcoal briquette. The charcoal, along with the mineral carbon and the brown coal, serves as a heat source. The borax is a press release agent, while the starch is a binder. The sodium nitrate and the sawdust both assist with ignition and the starch is a binder. Other different types of charcoal briquettes may be marketed as “natural.” In this case, they may only contain charcoal and starch. Still other different types of charcoal briquettes contain additional